Early Journal Content on JSTOR, Free to Anyone in the World

This article is one of nearly 500,000 scholarly works digitized and made freely available to everyone in the world by JSTOR.

Known as the Early Journal Content, this set of works include research articles, news, letters, and other writings published in more than 200 of the oldest leading academic journals. The works date from the mid-seventeenth to the early twentieth centuries.

We encourage people to read and share the Early Journal Content openly and to tell others that this resource exists. People may post this content online or redistribute in any way for non-commercial purposes.

Read more about Early Journal Content at http://about.jstor.org/participate-jstor/individuals/early-journal-content.

JSTOR is a digital library of academic journals, books, and primary source objects. JSTOR helps people discover, use, and build upon a wide range of content through a powerful research and teaching platform, and preserves this content for future generations. JSTOR is part of ITHAKA, a not-for-profit organization that also includes Ithaka S+R and Portico. For more information about JSTOR, please contact support@jstor.org.

SOME TESTS ON MOTOR-DRIVEN DEEP-WELL PUMPS[1]

By I. W. Fisk and P. S. Biegler

The data presented in this paper have been collected at the suggestion of Mr. F. C. Amsbary, manager of the Champaign & Urbana Water Company. Originally, the object of the work was to correct the low power factor of the power plant load, but other problems arose in the course of this investigation, some of which are discussed below.

A preliminary test showed that the generator in the plant was overloaded, due to poor power factor of the load. This low power factor was undoubtedly due to the fact that the 10-horse-power induction motors driving the well pumps were, as a rule, too large for their loads. They have been replaced by smaller motors as rapidly as possible, thus raising the power factor of the system and relieving the generating apparatus.

Table 1 is a summary of data taken March 7, 1917, to show the general condition of the pumping units at the present time. From similar data attempts have been made to formulate some relations between speed of pump and efficiency, length of stroke and efficiency, etc., but mechanical conditions in the pumps and wells apparently play such a large part in the results of the tests that no such relations have been shown from these data. It may be observed that the efficiencies vary all the way from 19 to 61 per cent, the average over-all efficiency being 46.4. The efficiencies are low when the slips are great, indicating poor condition of valves or pistons. The last columns are of considerable interest since they show the improvement in power factor on the electric motor when a 5 horse power motor is used instead of one of 10 horse power. But, for these loads, there is little difference in motor efficiencies, the results slightly favoring the 10 horse power motor. The measurements shown in this table were obtained with a good degree of accuracy, except those of the head. This was obtained on the

---

[1] Read before a meeting of the Illinois Section at Urbana on March 14, 1917.

TABLE 1

General operating condition of motor-driven deep-well pumping units on March 7, 1917

WELL NO.	TYPE PUMP	SPEED R. P. M.	KW. INPUT	H. P. INPUT	H. P. MOTOR	H. P. INPUT TO PUMP	STROKE PUMP	BORE	NOMINAL DISPLACEMENT	GAL. PER MIN. ACTUAL	NOMINAL GAL./MIN.	NOMINAL SLIP GAL./MIN.	SLIP IN PER CENT	ACTUAL HEAD	ACTUAL W. H. P.	ACTUAL EFF. PER CENT	MOTOR EFFIC.		MOTOR P. F.	
																	5 h.p.	10 h.p.	5 h.p.	10 h.p.
13	A	18.0	4.37	5.85	10.0	5.5	15	7.43	5.65	86.0	101.5	15.5	15.3	156.0	3.38	57.8	84	86	82	69
15	A	23.0	6.04	8.07	10.0	7.1	15	7.43	5.65	97.5	130.0	32.5	25.0	158.2	3.89	48.2		87		76
14	A	25.5	3.94	5.28	10.0	4.5	15	5.75	3.38	66.5	86.2	19.7	22.8	152.2	2.55	48.2	84	86	77	62
12	A	23.7	5.35	7.16	10.0	6.25	15	7.43	5.65	111.0	134.0	23.0	17.2	160.8	4.48	62.6		87		72
11	A	25.0	3.54	4.74	5.0	4.0	15	5.75	3.38	74.5	84.5	10.0	11.8	153.8	2.89	61.0	84	85	74	59
17	A	24.0	3.41	4.56	10.0	3.9	18	5.75	4.06	62.0	97.4	35.4	36.3	151.4	2.36	51.8	84	85	74	58
1	A	18.6	4.27	5.71	5.0	4.8	15	5.75	3.38	51.0	62.9	11.9	18.9	149.4	1.92	33.6	84	86	78	65
2	A	28.5	4.10	5.48	5.0	4.6	15	5.75	3.38	59.0	96.2	37.2	38.7	150.8	2.24	40.8	84	86	77	63
6	A	27.5	4.15	5.55	5.0	4.65	15	5.75	3.38	48.5	93.0	44.5	47.8	148.8	1.82	32.8	84	86	78	64
3	A	28.0	4.45	5.95	5.0	5.0	15	5.75	3.38	83.5	94.7	11.2	11.8	155.2	3.28	60.2	84	86	79	66
19	A	25.3	3.48	4.67	10.0	3.9	15	5.75	3.38	59.4	86.0	26.6	30.4	150.9	2.26	48.4	84	85	74	58
21	A	29.0	4.04	5.42	5.0	4.53	15	5.75	3.38	67.0	98.6	31.6	32.1	152.3	2.57	47.4	84	86	77	63
5	A	23.0	23.58	9.8	10.0	4.08	15	5.75	3.38	40.5	77.8	37.3	47.7	147.5	1.51	31.4	84	85	70	59
16	B	23.1	4.60	6.17	10.0	5.3	18	5.75	4.06	86.0	93.7	7.7	8.2	156.0	3.38	54.8	84	86	80	68
7	C	29.0	4.87	6.52	5.0	5.45	18	5.75	4.06	75.0	117.8	42.8	36.3	153.8	2.91	44.6	84	86	80	68
8	C	26.4	4.71	6.32	5.0	5.28	18	5.75	4.06	45.5	107.5	62.0	57.6	148.1	1.70	26.9	84	86	80	67
18	C	24.0	4.05	5.43	10.0	4.65	18	5.75	4.06	28.0	97.4	69.4	71.1	145.0	1.04	19.2	84	86	78	64
4	C	23.6	4.28	5.74	5.0	4.8	18	5.75	4.06	53.5	95.8	42.3	44.0	149.7	2.02	35.2	84	86	78	65
20	E	21.3	5.20	6.97	7.5	5.96	15	7.43	5.65	106.0	121.0	15.0	12.4	159.8	4.27	61.2		87		72
22	E_c	26.5	5.18	6.95	5.0	5.8	18	5.75	4.06	101.0	108.0	7.0	6.5	158.8	4.04	58.2	84	86	82	71
10	E	29.5	5.05	6.77	10.0	5.9	15	5.75	3.38	81.8	99.8	18.0	18.0	154.3	3.20	47.3	84	86	82	71
Total				124.3						1483.2	2083.8	597.2			57.71	46.4				
average				5.93						70.6	99.2	28.4	28.6		2.75					

assumption that the water level falls off with the rate of pumping water in all wells, following the relation existing between these two quantities in Well 10, as shown in Figure 4, the data for this well having been taken with great care. In other wells the clearance between pump barrel and well casing was too small for the apparatus available for measuring head with the pump in operation.

In testing motor-driven reciprocating pumps considerable difficulty is encountered from the pulsating character of the work done. The current drawn from the line by the driving motor fluctuates rapidly as shown by the oscillogram, Figure 1. The steady quantity is voltage at the motor terminals, the other curve is the current, which is seen to change rapidly during four-fifths of a second, as shown in the figure. There are no suitable indicating instruments for measuring such fluctuating power or current, but a watthour meter may be used for measuring energy over a given period and from this the average power may be obtained. For all tests discussed in this paper, a rotating standard watthour meter was used to measure the average power required by the motors.

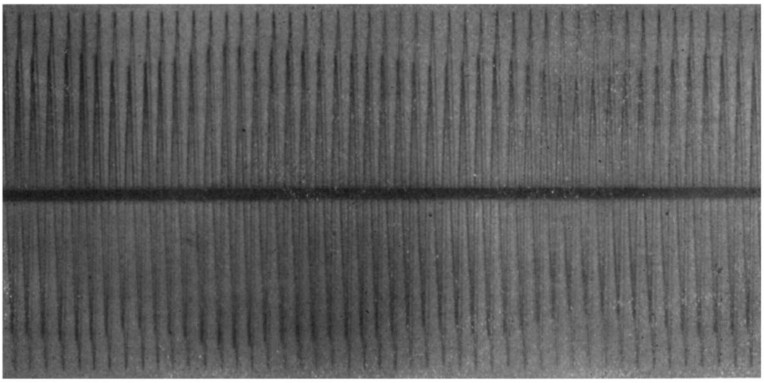

FIG. 1. OSCILLOGRAM OF MOTOR CURRENT

For the measurement of the discharge of the pumps a calibrated bucket was used, as shown in Figure 2. This bucket has holes in the bottom which may be changed according to the rate at which water is delivered by the pump. A glass gage registers the height of water in the bucket and this gage reading may be converted into gallons per minute by reference to Figure 3. By this means any peculiar characteristics of the discharge may be noted which might

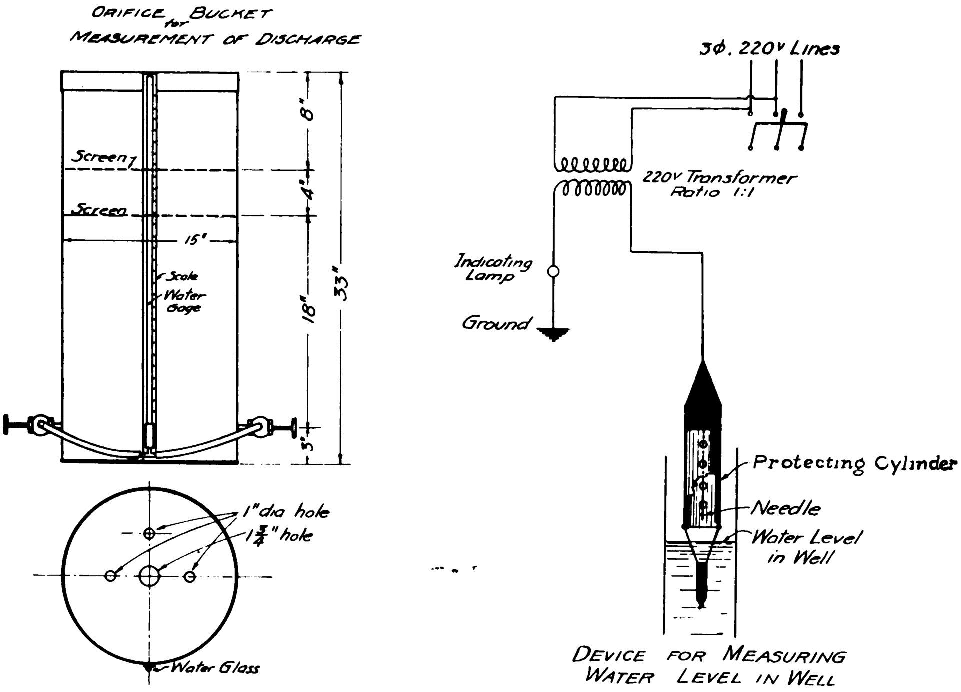

FIG. 2. APPARATUS FOR DETERMINING THE YIELD OF WELLS

pass unobserved if the discharge is measured, for instance, by taking the time required to fill a tank. This device was originally designed by Prof. M. L. Enger, University of Illinois.

Figure 2 also shows apparatus developed by the authors for the measurement of the height of water in the well. It is easily made sensitive to a change in water level of 0.1 inch, the only difficulty being the small space within the well casing into which the device must be lowered to get the water level while the pump is in operation. The device is easily lowered into the well when the pump has been pulled.

From the diagram of connections it is seen that when the end of the circuit being lowered into the well touches the water, a circuit, established through the ground, is complete, lighting the indicating lamp. The use of a transformer in this circuit is simply to avoid grounding one of the service wires. The needle forms one end of the electric circuit and is protected from grounding on the iron

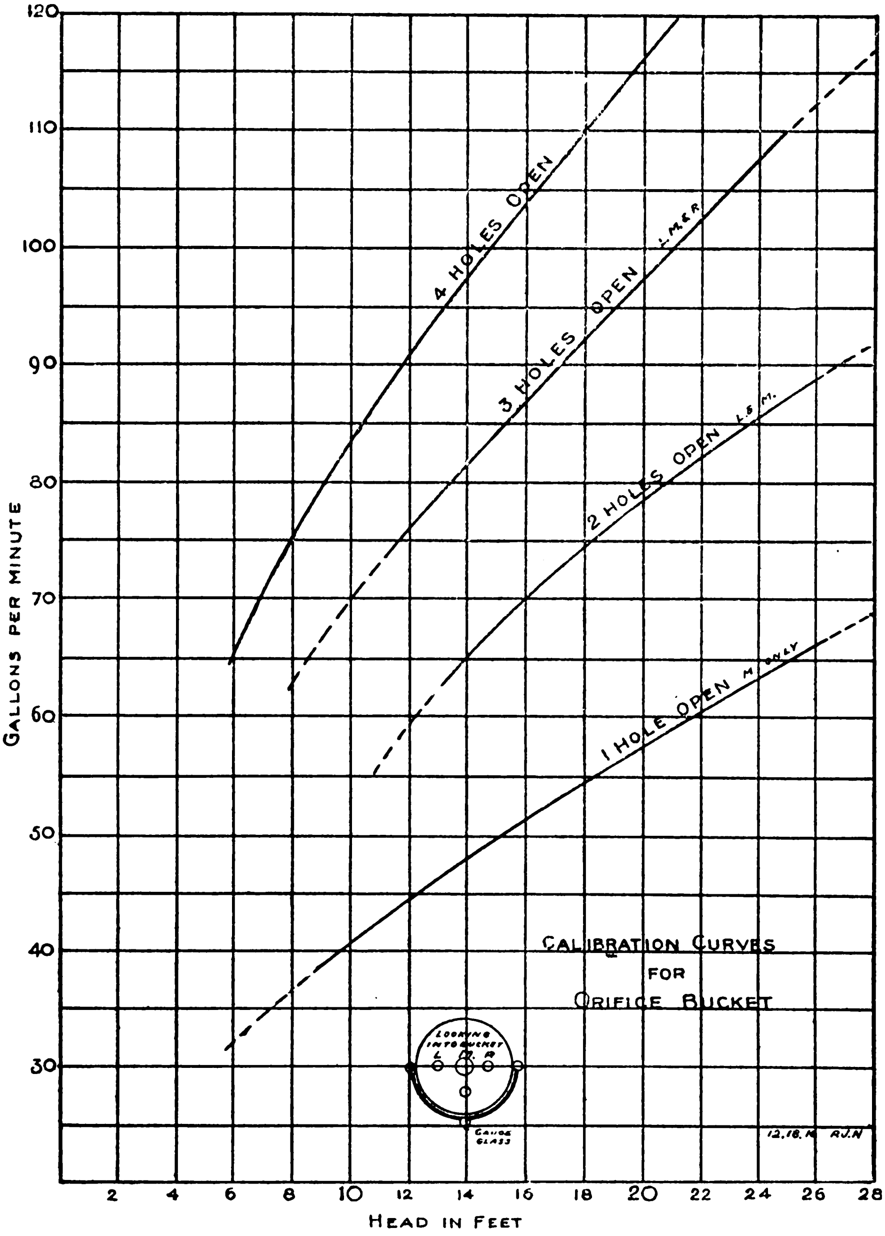

FIG. 3. CURVES OF THE DISCHARGE OF THE ORIFICE BUCKET

pipes by means of a shielding cylinder from which the needle is insulated.

For the reason that it was impossible to get at any definite relations regarding pump speed, water discharged, slip and efficiency from such data as those shown in Table 1, in which the pumps were not all in the same mechanical condition of operation, it became evident that a more detailed study of one pumping unit might yield the characteristics desired. Accordingly, Well 10 was chosen for these tests, principally on account of the ease with which the water level in it could be measured with the pump in operation, and also because the pump in this well was in average mechanical condition, having been in service about five years.

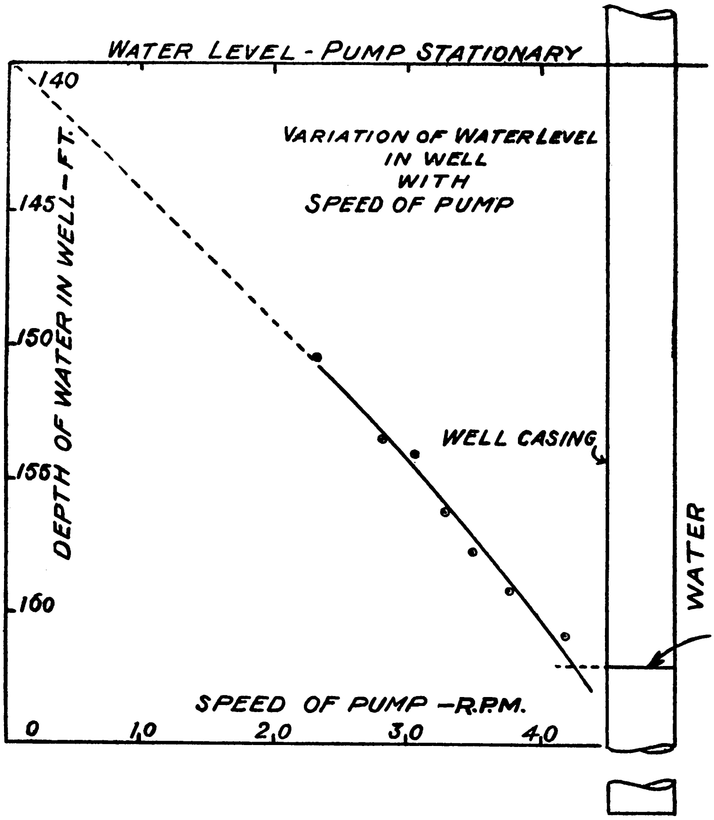

FIG. 4. EFFECT ON WATER LEVEL OF SPEED OF PUMP

TABLE 2

Characteristics of pumping unit, varying speed (10 horse power motor)

MOTOR PULLEY	R. P. M. PUMP	MOTOR K. W.	INTAKE H. P.	MOTOR		PUMP IN-TAKE H. P.	GAL./MIN.	HEAD	OUTPUT H. P.	PUMP EFF.	OVER-ALL EFF.	K. W. H. PER 1000 GAL.	GAL. PER MIN. NOMINAL	NOMINAL SLIP	
				Eff.	P. F.									Gal./ min.	Per cent
inches															
4	22.25	3.75	5.03	85.5	61.0	4.3	57.0	150.75	2.22	51.7	44.2	1.096	75.2	18.2	24.2
5	27.25	4.64	6.22	86.0	68.0	5.35	74.0	153.75	2.88	53.8	46.3	1.045	92.0	18.0	19.7
5½	29.5	5.05	6.77	86.5	70.5	5.85	81.8	154.33	3.20	54.7	47.3	1.028	99.8	18.0	18.0
6	31.75	5.42	7.26	86.5	73.0	6.28	89.0	156.5	3.52	56.0	48.5	1.014	107.2	18.2	17.0
6½	33.75	5.78	7.75	87.0	75.0	6.75	95.7	158.0	3.81	56.5	49.2	1.005	114.0	18.2	16.1
7	36.5	6.25	8.37	87.0	77.0	7.29	105.0	159.5	4.24	58.2	50.7	0.992	123.2	18.2	14.8
8	41.0	7.08	9.48	87.0	79.0	8.25	120.0	162.25	4.92	59.6	51.8	0.984	138.4	18.4	13.3

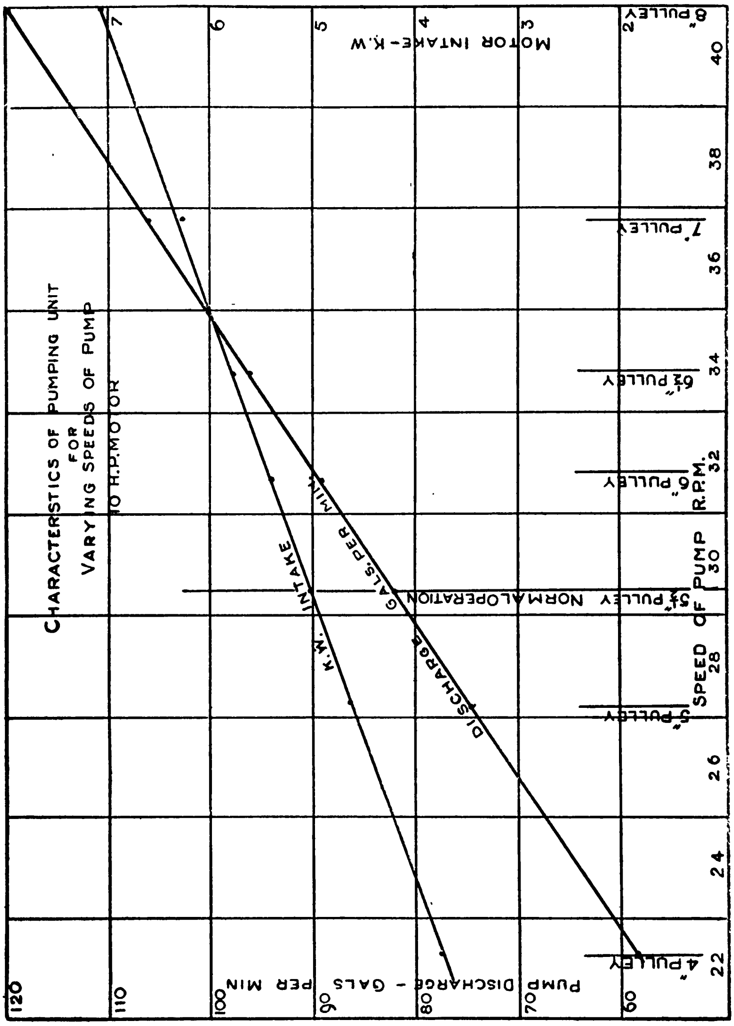

FIG. 5. EFFECT OF SPEED OF PUMP ON DISCHARGE AND POWER CONSUMPTION

In order to get at the pumping unit characteristics for a variation of speed of pump and water discharged, a number of pulleys were arranged for use on the driving motor, of such sizes that pump speeds of from 22 to 41 r.p.m. were obtained. The results of this test are shown in Table 2. Figure 4 shows the change of the water level in the well as the pump speed was increased. It may be observed that this curve bends down at the higher speeds, that is, the water level goes down faster as the discharge of the pump increases.

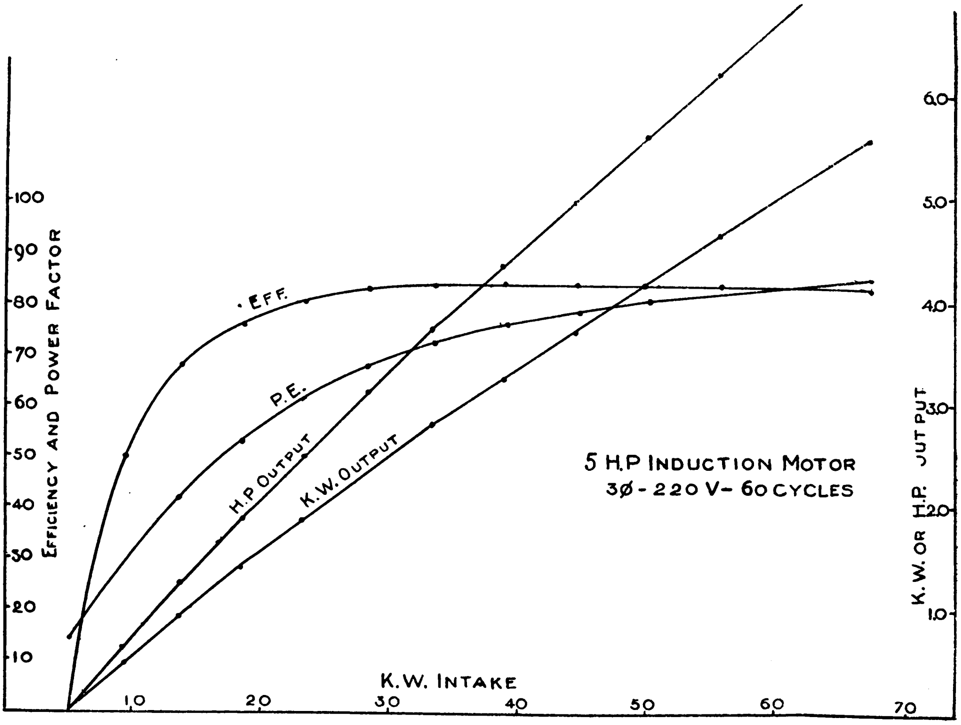

FIG. 6. CHARACTERISTICS OF 5 HORSE POWER MOTOR

Other original data taken for varying speeds of pump are shown in Figure 5, from which it is seen that both the power required by the motor and the water discharged from the pump are linear functions of the speed, within the range taken. Due to the changing head against which the water is pumped, under these conditions, and the change in efficiency of the pumping unit, this direct relation would probably not hold for wider variations in speed. In this case, however, the increase in efficiency at higher speeds appears to just about offset the increased head through which the water must be lifted.

Figures 6 and 7 show the electrical characteristics of 5 and 10 horse power induction motors used with these wells. These curves are here plotted against kilowatt intake of the motor, since this is the readily measurable quantity. It may be observed that the efficiency of both motors remains fairly constant over a wide range of loads, and that the 10 horse power motor efficiency is slightly higher than that of the 5 horse power motor. In the matter of power factor, however, it is evident that this may be very low if the motor is underloaded. Although low power factor does not lower the efficiency of the motor or pumping unit, it has a very serious effect upon the generating plant. It may result in drawing full

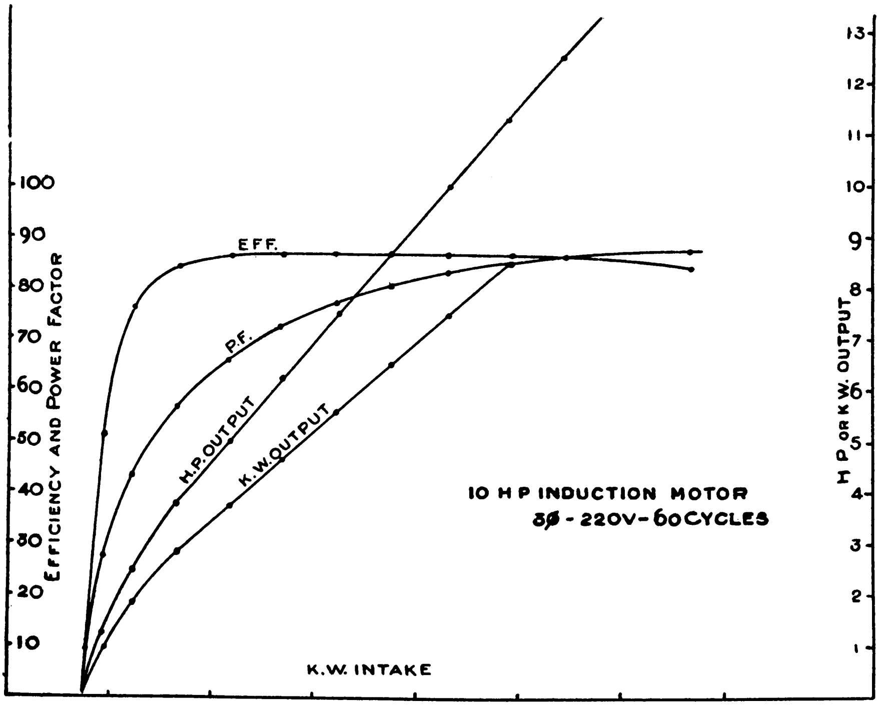

FIG. 7. CHARACTERISTICS OF 10 HORSE POWER MOTOR

load current from the electric generator although the actual power delivered is far less than normal. A further increase of load on the system, then, will require additional generating capacity in the plant with greatly increased investment and operating expense, and will result in only partially loaded prime movers. Even if the electrical energy for operating the wells is purchased, there is a tendency, at the present time, to penalize low power factor in rate schedules for large customers. It is of first importance, then, to select motors of such size that the power factor of the system will be reasonably high, or to resort to the use of a synchronous motor for power factor correction.

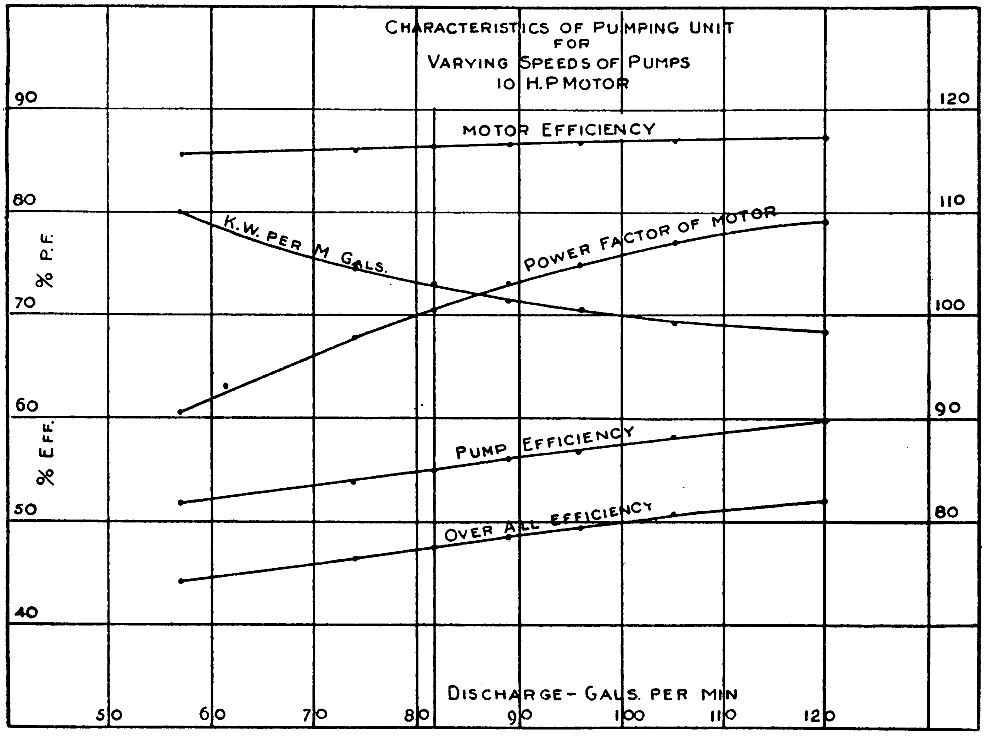

FIG. 8. EFFECT OF SPEED VARIATIONS ON CHARATERISTICS OF 10 HORSE POWER PUMP

Figure 8 shows the change in power factor of the 10 horse power motor as the discharge is increased (by speeding up pump) from about 57 gallons per minute to 120 gallons. The power factor

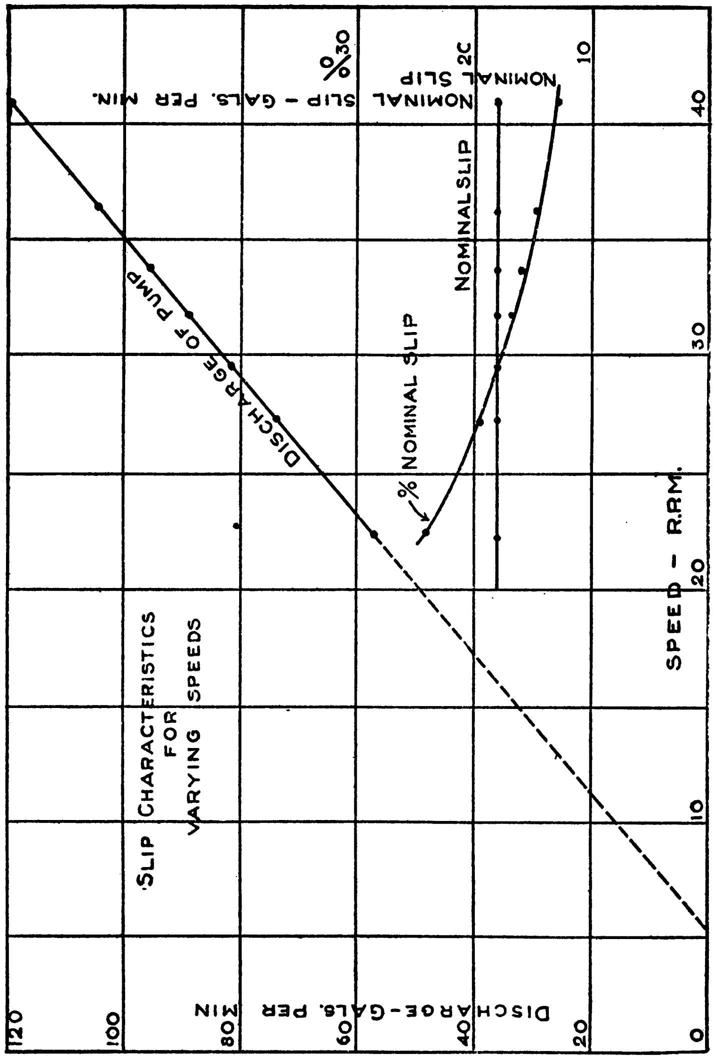

Fig. 9. Slip of Pump at Different Speeds

thus changes from a very poor one, at light load, to a reasonably good one at high speed. The motor efficiency increases but little through this range of loads, but the pump efficiency increases to a marked extent and the over-all efficiency curve is practically parallel to it. This increased efficiency at high speeds is shown from another point of view by means of the curve of economy, kilowatt-hours per 1000 gallons pumped.

In order to explain this increased efficiency at high pumping speeds, curves of slip are shown in Figure 9. It is seen that, with a given column of water in the pump barrel and discharge pipe, the water will leak past the pistons and valves at the same rate whatever the speed of the pump. The nominal slip is here used, i.e., the slip calculated on the assumption that the effect of overlapping travel of the pistons is zero. The percentage of slip, then, decreases with increased speed and thus the efficiency rises for high discharge rates. The friction losses in the pump head should increase in direct proportion to the speed, affecting the pump efficiency but little.

It is well known that the speed of a reciprocating pump cannot be increased indefinitely on account of the increased wear and tear involved. But, in a well designed pump, one which runs smoothly and with minimum shock, it is probable that speeds might be raised to advantage even at the expense of increased maintenance For instance, if three wells are in operation and more water is needed it might be economical to increase the speed of the three pumps and pay a possibly increased operating expense, rather than increase the investment by driving and equipping a new well. The increased efficiency of the pumps operating at higher speed also makes the three well proposition look more favorable.

In conclusion, the authors feel that the study of motor-operated deep-well pumps is worthy of considerable experimental investigation, and the present paper is only a preliminary report on the problem at hand.